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A PRELIMINARY REPORT ON STATIC STRENGTH TESTING FOR USE IN THE DEVELOPMENT OF OCCUPATIONAL PHYSICAL SELECTION STANDARDS

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ABSTRACT

Assessing the strength capabilities of recruits is a necessary step in the development of occupational physical standards for all trades in the Canadian Forces. This study reports preliminary data on static strength tests and equipment designed to measure the strength capabilities of CF personnel. The equipment and testing procedures were adapted from the existing literature and appeared to offer valid strength data that were reliable.

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INTRODUCTION

Since many trades in the Canadian Forces (CF) are physically demanding, a selection procedure that includes standards based on the physical demands of the trades would contribute to the effective assignment of personnel. This effective assignment in turn may reduce attrition levels within trades. Consequently, DCIEM has undertaken a project aimed at developing occupational physical selection standards (OPSS) for all trades in the CF.

One of the basic physical requirements which has been identified across military occupations is strength (1,2,3). The definitions and the method of measurement of strength has varied in the previous work on strength (2,3). The OPSS study is exploring the use of static strength measures as one method of representing the strength capabilities of an individual. There are many practical reasons for using measures of static strength instead of dynamic strength. Static strength testing is, in general, less time consuming, less fatiguing and safer for the subject (2,4,5,6). Also, the standardization of static strength tests is less complicated (4,5). Therefore, given that a small number of static tests can provide meaningful strength data and yet remain fairly simple in administration, data collection and analysis, this method may prove to be useful to the OPSS study for screening individuals.

STATIC STRENGTH APPARATUS AND RECORDING EQUIPMENT

In order to measure the maximal voluntary contraction of various muscle groups, the development of an adjustable strength testing apparatus was required. A strength testing apparatus was adapted from the work of previous researchers (7,8). This apparatus and its accompanying recording equipment are shown in Figure 1.

The strength testing rig consisted of two vertical, metal standards and a wood base enclosed in a metal frame. When required for a specific strength test, a metal cross-piece, with an attached pulley and a wood support could be placed between the standards. A tension-compression load cell, with a maximum capacity of 2225 Newtons (500 lbs), was affixed to the wood base via metal plates. An adjustable chain-cable assembly and lifting bar or nonstretchable belt provided the connection between the subject and the load cell. All contact surfaces between the subject and the apparatus were padded, but did not hinder the subject's performance.

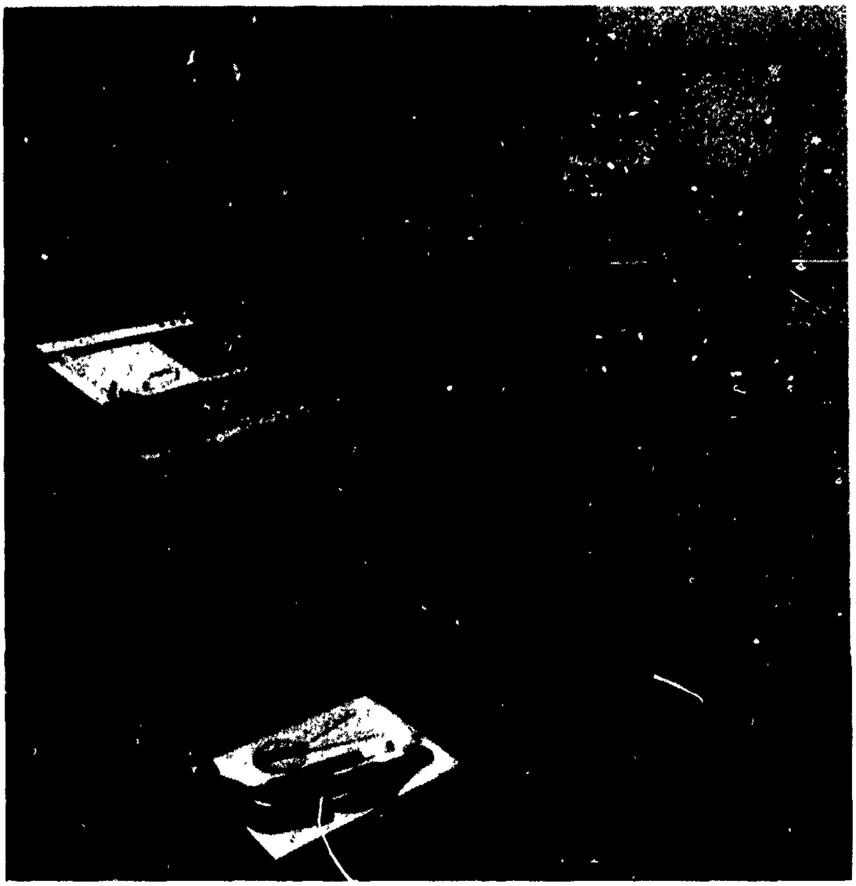

Figure 1: The Static Strength Testing Apparatus

The original strength testing device described in the literature had a spring loaded Stoelting grip dynamometer to measure the forces (7,8). The dynamometer was modified with a potentiometer attached to its dial, so that the registered force could be transferred to an electronic unit. That unit was designed to reject the first second of force data. The electronic unit integrated the force over the next three seconds, and this averaged force was displayed as a digital readout. A load cell was used in the present study instead of a modified dynamometer, since the load cell system remained calibrated for a longer period of time (9).

The forces measured by the load cell were all in tension. The output from the load cell was recorded in two separate ways:

1) a digital indicator recorded the peak or maximum force level applied to the load cell;
2) an X-Y plotter, modified with a timer, recorded a continuous tension measure over five seconds. An averaged strength value could then be calculated from the continuous tension recording.

A more detailed description of the strength rig, load cell and recording equipment appears in the Appendix A.

RELIABILITY

i) Static Strength Apparatus and Recording Equipment

The initial tests of the static strength apparatus and recording equipment were designed to ensure that the load cell was correctly measuring the forces applied to it, and that this output was consistent over repeated trials. The method chosen to assess the reliability of the data obtained from this system was to apply various known forces to the load cell and compare the recorded outputs on the X-Y plotter.

The apparatus was set up with the metal cross-piece in place between the vertical standards. Weights were suspended from the chain-cable assembly, which passed over the pulley and was connected to the load cell. The pen on the X-Y plotter recorded the displacement from the baseline and these deflections were measured to the nearest 0.05 centimeters. A number of metal plates, each weighing approximately 4.54 kilograms, were used in the force application. To ensure that the forces applied to the load cell were consistent over repeated trials, the output on the digital indicator was also recorded. The digital indicator measured the force in pounds and this value was converted to Newtons (1 pound = 4.45 Newtons). After these two output recordings were noted, the procedure was repeated so that data were collected using 44.5, 89.0, 133.5, 178.0 and

222.5 Newton forces. The forces were administered in a random order and three trials per day, for two days, were conducted. The data for the forces applied to the load cell and the corresponding displacements of the pen on the X-Y plotter are shown in Table 1.

An analysis of variance (ANOVA) was completed on the data in Table 1 (10). The results of the ANOVA appear in Table 2. The various forces produced significantly different X-Y plotter deflections at the 0.05 level. There was no significant difference, at the 0.05 level, between the trials. The data were then tested to establish if the relationship between the various applied forces and their corresponding mean displacement values on the X-Y plotter was linear (10). The analysis revealed that 99% of the variation in the displacements of the X-Y plotter were caused by changes in the applied force and that the relationship was linear.

Using correlation techniques, the concept of reliability was quantified (11). The degree of reliability of the testing apparatus and recording equipment can be defined as the correlation between the results of the trials on two different occasions. Reliability coefficients for the six trials were calculated and the values were all greater than 0.99 (Table 3).

Table 1. The Measured Displacements on the X-Y Plotter over Six Trials

Known Forces (in Newtons)	X-Y Plotter Deflections (centimeters)					
	1	2	3	4	5	6
44.5	0.50	0.50	0.50	0.50	0.50	0.45
89.0	1.00	1.00	1.00	0.95	1.00	1.05
133.5	1.50	1.50	1.50	1.55	1.50	1.55
178.0	2.05	1.90	2.05	2.05	2.00	2.10
222.5	2.55	2.50	2.55	2.50	2.55	2.65

Table 2. Analysis of Variance for Data of Table 1

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Square	F-ratio
between forces	15.86	4	3.965	7980*
within forces	0.05	25	0.002	
between trials	0.02	5	0.004	2.67**
residual	0.03	20	0.0015	
TOTAL	15.91	29		

* significant at 0.05 level
** not significant at 0.05 level

Table 3. Reliability Coefficients for the Initial Tests of the Static Strength Apparatus and Recording Equipment

Trials		2	3	4	5	6
	1	0.9978	1.0000	0.9987	0.9997	0.9995
	2	---	0.9978	0.9962	0.9992	0.9984
Trials	3	---	---	0.9987	0.9997	0.9995
	4	---	---	---	0.9981	0.9977
	5	---	---	---	---	0.9995

These are computer generated numbers which have not been expressed to significant digits.

ii) Static Strength Tests

The second set of tests was developed to assess the reliability of both the strength rig and a number of static strength tests. These static strength tests were adapted from the literature and are described in Appendix B (7,8). Data were collected on four subjects, three males and one female, using a test-retest methodology (12). Each subject performed the test-retest trials, involving the eleven static strength tests, on separate days.

Peak strength scores on the digital indicator and continuous tension measures on the X-Y plotter were recorded. This study used the peak strength scores as the measure of the subjects' strength, instead of an averaged value calculated from the continuous tension measure, as recommended by Caldwell et al. (13). The peak strength scores were used for two reasons. First, Kroemer and Marras (6) have found that the same interpretation of the results can be obtained by using either peak or averaged strength data, provided the protocol discussed in Caldwell et al. (13) was utilized. This protocol involving the collection of data is specified in Appendix B. Second, the peak strength data were easier to interpret and would therefore be more useful for analysis in recruiting centers, where the development of this methodology is eventually targeted. The peak strength data from the static tests appear in Table 4.

The continuous tension measures were important because they provided information which ensured that the data collection was correctly standardized. For each strength test, the protocol required the subjects to reach a maximum exertion in the first second of a test and then maintain that maximum exertion level for another four seconds. Upon inspection of the continuous tension measures for each test, the subjects appeared to experience greater difficulty in maintaining a maximal exertion level in the lifting strength tests. The lifting strength tests were not as well standardized as the other tests in respect to the restrictions applied to body position and joint mobility. This greater potential for minor changes in body attitude may account for the increased variability displayed in the retention of the maximum exertion levels of the lifting strength tests.

Reliability coefficients, calculated for each subject's performance for the entire strength battery, ranged from 0.89 to 0.97 (Table 5). The reliabilty coefficients for the eleven strength tests ranged from 0.49 to 1.00 (Table 6). By squaring the reliability coefficient, i.e. r^2, the amount of variation in one testing trial that could be accounted for by another testing trial was calculated. The range for the r^2 values of the strength tests was 0.24 to 1.00 (Table 6).

Table 4. The Test-retest Data from the Static Strength Tests

		Subject			
		1 (M)	2 (M)	3 (M)	4 (F)
Test	Trial				
1. Elbow Flexion at 90 degrees	1	347	356	285	151
	2	329	427	285	134
2. Arm Pull	1	587	543	427	383
	2	552	659	418	267
3. Shoulder Flexion at 135 degrees	1	134	116	125	53
	2	134	116	102	40
4. Shoulder Flexion at 45 degrees	1	107	71	98	27
	2	116	71	107	18
5. Back Extension	1	650	650	890	623
	2	712	579	676	436
6. Back Flexion	1	445	712	810	534
	2	614	587	685	427
7. Lift at 40 cm.	1	1415	1344	1291	650
	2	1291	1335	952	641
8. Lift at 81 cm.	1	1531	1807	1095	721
	2	1059	1469	1469	757
9. Lift at 110 cm.	1	329	668	721	303
	2	320	712	703	285
10. Lift at 140 cm.	1	659	863	1032	285
	2	863	961	792	427
11. Lift at 190 cm. or max. height	1	543	445	454	320
	2	516	374	543	320

The data were originally measured to the nearest pound and then multipied by 4.45 to calculate the metric force equivalents in Newtons. Male and female subjects are denoted by M and F respectively.

Table 5. Reliability Coefficients (r) for the Performance of the Entire Strength Battery by Each Subject

Subject	r
1	0.94
2	0.97
3	0.89
4	0.93

Table 6. Reliablility Coefficients (r) and Their Squared Values (r^2) for the Eleven Static Strength Tests

Test	r	r^2
1. Elbow Flexion at 90 degrees	0.96	0.92
2. Arm Pull	0.88	0.77
3. Shoulder Flexion at 135 degrees	0.97	0.94
4. Shoulder Flexion at 45 degrees	1.00	1.00
5. Back Extension	0.49	0.24
6. Back Flexion	0.51	0.26
7. Lift at 40 cm.	0.90	0.81
8. Lift at 81 cm.	0.61	0.37
9. Lift at 110 cm.	0.99	0.98
10. Lift at 140 cm.	0.79	0.62
11. Lift at 190 cm. or max. height	0.77	0.60

DISCUSSION

The initial reliability tests of the strength apparatus and the recording equipment resulted in very high coefficients (11,12). This method of comparing the changes in the displacements on the X-Y plotter when applying known forces to the load cell, can be used as a calibration procedure in future experiments.

The results of the second set of reliability tests were compared to similar work in the literature. Yates et al. (8) found reliability coefficients of greater than 0.90 for the elbow flexion, shoulder flexion and back extension tests. The reliability coefficients of the lifting tests ranged from 0.66 to 0.91. Apart from the back extension and flexion tests, the present study's coefficients (Table 6) compared favourably and fell within their suggested acceptable range for measures of strength (8). The lower reliability coefficients of the two tests of back strength (0.49 and 0.51) may reflect the greater difficulty experienced in attempting to standardize these particular tests. Minor adjustments in the apparatus and testing procedures may reduce the variability between the test-retest scores and therefore increase their reliability. These adjustments include the addition of an improved support for the mid-abdomen or back area and a redesigned adjustable belt for placement around the shoulders, that will ensure a more standardized posture among the subjects.

It has been suggested that a test or measure may not be useful if its r^2 value is below 0.60 (14). As shown in Table 6, only three of the tests had values lower than 0.60. These were the two back strength and one of the lifting strength tests. However adjustments made to the apparatus, as previously mentioned, and changes in the test procedures, such as standardizing the posture of the subjects in the 81 centimeter lift test, may increase the r^2 values of these three tests.

CONCLUSIONS

It appears the static strength apparatus and recording equipment can be used to obtain reliable data. When the specific strength tests and testing procedures are finalized for the OPSS study, a further analysis of reliability will be required on a larger sample of subjects. The strength data and the method of data collection may prove to be a valuable asset in establishing physical selection standards for CF trades.

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APPENDIX A

Description of the Static Strength Apparatus and the Recording Equipment

1. The Static Strength Rig

Some of the important dimensions of the strength rig are:
1) a square 87.0 centimeter base;
2) two vertical standards made of 3.8 centimeter tubing and including the base, they stand 155.0 centimeters above the floor;
3) two side supports (3.8 X 2.0 X 137.0 centimeters) which help retain the stability of the standards;
4) a cross-piece between the standards made of 3.8 centimeter square tubing having an attached pulley, 6.5 centimeters in diameter;
5) a wood support (38.0 X 76.0 centimeters) which attaches between the standards via four metal brackets.

To link the subject to the load cell, an adjustable chain and cable (105.0 and 110.0 centimeters in length, respectively) were used. The subjects either held a bar, 2.5 centimeters in diameter and 31.0 centimeters in length, or were attached to the system via adjustable belts, 5.0 centimeters in width. A stool and a removable elbow rest, which attached to the wood support, were used in some of the tests.

2. The Load Cell

The applied forces were measured by a 2225 Newton capacity load cell from the Lebow Associates Incorporated (model number 3169). Some of its specifications are:
1) output of 2.141 Mv/V at rated capacity;
2) nonlinearity +/- 0.08% of the rated output;
3) hysteresis +/- 0.12% of the rated output;
4) repeatability +/- 0.02% of the rated output;
5) overload capacity 150% of nominal capacity;
6) maximum excitation voltage of 20 volts DC or AC rms.

3. The Recording Equipment

There were two methods of recording the data. First a peak strength value was recorded by a Lebow Peak Indicator (model 7530) which also served as the power supply to the load cell. Second a spontaneous recording of the strength tests was made by a Hewlett-Packard X-Y Plotter (model 7035B). A timer, built in-house by DCIEM, permitted the plotter to record the continuous tension force over five seconds.

APPENDIX B

Description of the Static Strength Tests

1. elbow flexion *

   The subject sits facing the apparatus. The right elbow is rested upon a padded support, with the forearm in a vertical, mid-supinated position and the upper arm parallel to the floor. The link to the load cell is via a wrist strap, cable and chain.

2. arm pull

   The subject faces the apparatus and stands with feet shoulder width apart. With the right hand in a supine position and the elbow joint angle approximately 155 degrees, the subject pulls towards his/her body, without leaning backwards. A goniometer is used to adjust the angle at the elbow. The left hand grasps the horizontal frame bar for support. The link to the load cell is via wrist strap, cable and chain.

3. shoulder flexion (135 degrees) *

   The subject sits facing the apparatus. The back is kept straight and the right shoulder angle is 135 degrees, using the same attachments to the load cell as in the 45 degree shoulder flexion.

4. shoulder flexion (45 degrees) *

   The subject stands facing away from the apparatus, with the shoulder kept at a 45 degree angle to the body and the elbow joint fully extended. The angle between the upper arm and the trunk is set with a goniometer. A wrist strap, cable and chain assembly are used as a link to the load cell.

5. back extension **

   The subject stands upright, facing the apparatus, with feet shoulder width apart. A strap is placed around the subject's shoulders and attached at chest level to the load cell via cable and chain. The subject pulls backward, while stabilized by a wooden frontal support that extends from the waist to the knees.

6. back flexion

   The procedure is similar to the back extension, except the subject faces away from the apparatus. The subject pulls forward, while supported at the buttocks.

7. lifting strength

A series of lifts are performed, using both hands in a supine-positioned grip on a bar with the feet positioned at shoulder width. The subject is positioned so that his/her ankles (medial malleolus landmark) are a horizontal distance of 18 centimeters from the lifting bar. The subject's posture depends upon the lifting height. The lifting heights (40, 81, 110, 140 and 190 centimeters) test static strength of the legs, back or torso, arms and shoulders.

* Procedures similar to those reported by Yates et al. (8)

** Procedures similar to those reported by Kamon and Goldfuss (7) and Yates et al. (8)

Collection of the Static Strength Data

Before the static strength data could be collected, instructions to each subject on how to perform the strength tests was necessary. The protocol was adapted from the pre-test instructions discussed in Caldwell et al. (13). Initially the subjects were placed in the proper body position and specific body parts were stabilized, depending upon the requirements of the strength test. The subjects were instructed to exert a maximal effort following the count of 1,2,3 and go. A maximum exertion level was to be reached in the first second and then maintained for another four seconds. The subjects should not jerk the cable-chain assembly at any time during the exertion. At the end of the test, the experimenter would signal the subjects to stop their exertion.